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Environmental impact of meal service catering for dependent senior citizens in Danish municipalities

Henrik Saxe[1] · Jørgen Dejgård Jensen[2] · Susanne M. Bølling Laugesen[1] · Wender L. P. Bredie[1]

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Abstract

Purpose This study aims at defining and quantifying strategies to reduce the environmental impact caused by public and private Danish meal service supplying vulnerable home-dwelling senior citizens. Besides informing the scientific community, the goal is to inform decision makers at municipal and private commercial kitchens about their potential role in significantly reducing the environmental impact of the meal services by conscious, deliberate, and sustainable choices at each step of the meal-selection-production-packaging-delivery-chain.

Methods The Danish meal service is represented by five public and private meal producers with a combined annual production of 1.2 million main meals targeted at sustaining senior citizens living at home throughout nine municipalities. Forty-seven main meal recipes, divided into five categories, represent the typically available meals: vegetarian, fish/seafood, pork, poultry, and veal/beef. The study quantifies the environmental impact of the five meal categories by consequential life cycle assessment, using three functional units (mass, energy, and protein content) to investigate if differential impacts among the meal categories can support sustainability-improving strategies. Two impact categories, global warming and the monetized overall environmental impact, were calculated for each recipe, including all ingredients and processing. The environmental impacts of packaging, meal delivery, and food waste were estimated separately.

Results and discussion The average environmental impact of main meals with veal/beef were 5–7 times higher than the average impact of all other meals, and 8–11 times higher impact than the impact of the average vegetarian meal. The ranges reflect differences in the chosen functional unit and impact category. Differences among the non-beef meal categories were smaller, with vegetarian and fish/seafood meals having the lowest impact. The average global warming impact of the average main meals was 3.70 kg CO_2-eq and the overall monetized impact 0.62 €. Impact of waste was 0.03–0.18 kg CO_2-eq and 0.007–0.023 € per meal in kitchens, and 0.031–0.329 kg CO_2-eq and 0.006–0.041 € for consumers. The environmental impact of packaging added 0.07 kg CO_2-eq and 0.006 €, and meal delivery 0.026–0.435 kg CO_2-eq and 0.005–0.09 € per meal.

Conclusions The most important strategy for reducing the environmental impact of Danish meal service is to reduce the number of meals containing veal/beef. Vegetarian meals were rarely more sustainable than fish/seafood. Packaging, food waste, and delivery of meals played minor roles in the overall sustainability of Danish meal service, and the most efficient strategy to reduce the environmental impact of these activities would be to deliver meals weekly rather daily.

Keywords Consequential life cycle assessment · Dependent senior citizens · Global warming potential (GWP_{100}) · Meal service · Monetized environmental impact · Municipal kitchens

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✉ Henrik Saxe
HenrikSaxe@gmail.com

[1] Department of Food Science, Section for Food Design and Consumer Behaviour, Faculty of Science, University of Copenhagen, Frederiksberg C, Denmark

[2] Department of Food and Resource Economics, Section of Consumption, Bioethics and Governance, Faculty of Science, University of Copenhagen, Frederiksberg C, Denmark

1 Introduction

The aging populations are one of the most important demographic events of our time. Initially experienced by the more developed countries, the trend has recently become apparent in much of the developing world as well. Many countries are already in the midst of population aging, although at varying levels and time frames. In the EU, the share of people over 60 is presently around 15%, but that figure is expected to reach 30% by 2050 (UN 2015; Giacalone et al. 2016). Consequently, the demand for health care, welfare, and the economic impact of aging populations will increase in the coming years. In addition, the number of home-dwelling and senior citizens in care centers, who are dependent on different forms of personal care, will increase. One of the most important daily needs for such dependent senior citizens will be an adequate food provision. In several European countries, this is currently arranged by centralized catering of meals to individuals at home or to care centers on a daily or less frequent basis.

Low BMI and weight loss are risk factors for mortality in older people (Dey et al. 2001). Declines in skeletal muscle mass and strength are major contributors to increased mortality, morbidity and reduced quality of life in senior citizens (Nowson and O'Connell 2015). They need to have regular meals with sufficient energy (MJ) and protein nutrition, and to exercise in order to retain muscular strength. While an important focus in food catering for senior citizens is thus on healthy nutrition, little is known on the environmental impact of the catering services from choice of raw materials, recipes, processing, packaging, meal delivery, and waste.

It is well established that dietary composition (besides food waste) at the population level is one of the main drivers of global environmental impacts and has thus been placed at the heart of the 2030 Agenda for Sustainable Development (Sala et al. 2017). Production of foods and beverages is responsible for about half of the environmental impact caused by people's private activities, which in turn is responsible for about half of the overall environmental impact caused by our society; the remaining half is caused by industry. Therefore, the selection of environmental friendly meals can reduce the environmental impact of foods and beverages in the order of 35–65% (Saxe 2014). While producers at all levels have been doing their utmost to reduce food waste, the consumer still has a role to play in the overall 30% food waste from soil to table to leftovers.

There are many examples of the environmental impact of food and food consumption in general (Notarnicola et al. 2017; Saner et al. 2016; Saxe 2014; Saxe et al. 2017; Vermeulen et al. 2012). However, only few recent studies have addressed the environmental impact of public food services (Caputo et al. 2017; Jungbluth et al. 2016). Public meals are provided in different catering situations such as schools, hospitals, and elderly care. Public meals prepared for senior citizens in care centers and especially through home catering in the so-called meals on wheels are expected to grow in most parts of the world due to the increasing segment of the old and very old citizens. With predictions on how such food catering in the future will develop, it is important to assess the overall environmental impact of commercial and municipal catering kitchens for senior citizens. This could lead to strategies for rational and optimal use of resources for sustainable development in public procurement.

Although the current focus within the large municipal or private kitchens catering for senior citizens is on the health and well-being of its customers, both the overall environmental impact and health aspects have significant socioeconomic implications (Jensen et al. 2015; Tilman and Clark 2014; Hällström et al. 2017). In the present study, we evaluate the environmental impact and its monetized value of a wide range of meal choices and delivery strategies in the meal catering for dependent senior citizens in Denmark produced at five different central kitchens. To support the simple selection of sustainable meals and meal components, the meals were divided into five easily distinguishable categories expected to cause different environmental impacts: (1) vegetarian, (2) fish/seafood, (3) pork, (4) poultry, and (5) beef.

The study aimed to evaluate the environmentally most impacting steps across the whole meal-production-delivery-chain. Furthermore to suggest strategies on how to improve environmental sustainability of public meal service based on quantification and comparison of the environmental impacts of the five meal categories depending on the choice of relevant functional units (FU: mass, energy, or protein content) and important impact categories (global warming potential or the combined monetized impacts of 16 impact categories). The study outcome is aimed to contribute to rationalize the public debate and inform decision makers at municipal and private commercial kitchens about their potential role in reducing environmental impacts of the current meals on wheels catering for dependent senior citizens in Denmark and countries with a similar social service.

2 Materials and methods

2.1 Meal service providers, recipes, and nutrient content

Five Danish public and private large-scale meal service providers filled in a detailed questionnaire in advance of our visit to each kitchen in order to obtain Life Cycle Inventory (LCI) data on all ingredients for all recipes, associated energy

consumption for cooking/preparation and storage, packaging, meal delivery, and waste. To represent the meal service providers' overall production, we selected 45 of their most popular recipes (largest production volume) within five preselected categories, based on the main protein ingredient: beef, pork, chicken, fish/seafood, and vegetarian. To illustrate the fact that some more rarely served meals may differ considerably in environmental impact, we included two outliers in our analyses. There were nine representative recipes per category and a single outlier for both seafood and poultry (recipes are detailed in the Electronic Supplementary Material no. 1). Table 1 summarizes the nutrient data further specified in the Electronic Supplementary Material no. 2.

According to an ANOVA test, the protein, energy, and fat content do not differ significantly between the five meal categories. The meal categories differ significantly in their accessible carbohydrate and dietary fiber content. The explanation for this could be that vegetarian meals contain much more dietary fiber than non-vegetarian meals, while non-vegetarian meals contain much less accessible carbohydrate.

The five kitchens annually delivered over 1¼ million main meals to home-dwelling senior citizens in nine Danish municipalities. These are the data analyzed in this study, though the results also applies to catering at care centers except for the delivery impact. Table 2 shows that the same five kitchens also delivered ¾ million main meals to care centers in the same municipalities. An annual production of approximately 2 million main meals.

Det Gode Køkken delivered meals within Holstebro municipality, *Køkkenområdet* delivered within Hjørring municipality, *Dit Lokale Køkken* delivered within Herning municipality, *Mad og Måltider* delivered within Aabenraa municipality, all in Western Denmark. *Mad til Hver Dag* delivered meals to dependent senior citizens within five municipalities in Eastern Denmark: Albertslund, Allerød, Hillerød, Frederikssund, and Halsnæs.

2.2 Assessment of environmental responses and monetized effect

The environmental impact of the 47 recipes, i.e., the impact of ingredients (from the global market), cooking and storage (energy consumption), packaging, delivery, and waste (except waste treatment) was calculated by consequential life cycle assessment (cLCA) (Fig. 1). CLCAs seek to identify the environmental consequences of a decision or a proposed change in a system under study (oriented towards the future), which means that market and economic implications of a decision are taken into account (Earles and Halog 2011). More specifically, we selected data based on consequential modelling because:

(1) The goal of our study was to systematically compare the sustainability of meal categories produced for the senior citizens defined by their main protein ingredient. The further aim was to inform politicians as well as decision makers (LCA 2.-0 Consultants 2015; Weidema 2017) at municipal and private commercial kitchens of their potential role in reducing the environmental impact of the meal services by conscious, deliberate, and sustainable choices at each step of the meal-selection-production-delivery-chain, the choice of protein ingredients likely being the most important.
(2) It is important to consider market information in the LCI data of agricultural products (Zamagni 2012) since several of these originate from multi-functional sources. System boundary expansion in cLCA is more suitable than aLCA as this study involves meal ingredients obtained on the global market.

Table 1 Energy and nutrient content

Meal category	Per 100 g	KJ	Total protein	Accessible carbohydrate	Dietary fiber	Total fat
Vegetarian $n = 9$	Average	671	7.8	16.3	2.7	6.7
	SD	219	3.9	3.7	1.5	3.9
Fish/seafood ($n = 9$)	Average	585	6.9	9.0	1.1	8.3
	SD	314	1.6	5.2	0.3	6.4
Pork ($n = 9$)	Average	602	6.3	10.0	1.2	8.5
	SD	125	1.5	2.1	0.2	2.8
Poultry ($n = 9$)	Average	472	8.2	8.7	1.4	4.7
	SD	126	1.8	3.0	0.5	2.4
Beef ($n = 9$)	Average	555	7.6	10.6	1.4	6.4
	SD	119	3.1	2.4	0.5	1.5
One-way ANOVA (P value)		0.2994	0.7019	0.0006	0.0005	0.2131

Table 2 Number of meals annually catered to dependent senior citizens at home and in care centers by the five large-scale production kitchens

Producer name (kitchen location)	Delivered to private homes	Delivered to care centers
Mad og Måltider (Aabenraa)	145,599	121,807
Dit Lokale Køkken (Herning)	72,103	154,705
Mad til Hver Dag (Hillerød)	660,000	126,000
Køkkenområdet (Hjørring)	228,402	197,465
Det Gode Køkken (Holstebro)	130,000	168,000
Total	1,236,104	767,977

(3) We included the global warming potential (GWP, CO_2-eq measured over 100 years; IPCC 2013) associated with land use changes, since these are of particular importance for animal-based protein sources. LUC values were adopted from Audsley et al. (2009).

(4) The background data for the environmental assessment was obtained and constructed from the Ecoinvent database version 3.3 using consequential data only, and with assumptions and affected processes/technologies being pre-defined by the associated investigators (Ecoinvent 2016) using the Simapro 8.3 software. The Stepwise2006 version 1.05 method was applied to facilitate monetizing (Weidema 2009; Pizzol et al. 2015). We present characterized and weighed results. The Stepwise method combines methods from Impact 2002+ version 2.1 and EDIP 2003 with small modifications. Stepwise normalizes data by monetization expressed in Euro, thus calculating the potential socioeconomic cost of environmental externalities. The selection of meals prepared for the senior citizens is partly a nutritional and partly a political issue and we recognize that decision makers understand "money" better than "environmental impacts." Environmental friendly decisions on main meal composition for the senior citizens could have large-scale consequences.

(5) In April 2016, the Danish Council on Ethics called on the Danish government to regulate the consumption of "climate damaging foods" by placing taxes on those products with the highest associated emissions, i.e., beef.[1] Our study was inspired by this initiative, which could have large-scale consequences far beyond the Danish borders. Since we base our data on Ecoinvent, we accept the implicit marked choice as the current state-of-the-art. As half of the Danish beef supply originates from worn-out Danish dairy cows and most of the other half from import, an excess of beef, if the number of meal service meals with beef are reduced, would be reduced or channeled otherwise, e.g., export and/or a reduction in beef import. There is currently no export of Danish dairy-cow meat. Beef meals would be substituted with meals with pork, chicken, fish, or vegetarian for protein. This would result in small reduction in Danish pork export (Denmark at present exports 90% of its production), and an increased production of chicken, fish, and vegetable protein, all of which can be upscaled locally.

The scope of the present study included the response of 16 environmental impact categories associated with all activities, energy, and resource consumption in the complete production-delivery-chain depicted in Fig. 1.

The environmental impact of the five food services delivering the 47 different meals was calculated from soil to the doorsteps of dependent senior citizens. Transport impact was calculated according to Saxe (2014), depending on the origin of meal ingredients in a global marked. Delivery from kitchens to private homes was based on type of vehicles and average distances. Based on a separate questionnaire filled out by dependent senior citizens, we obtained data on waste in the private homes (Section 2.5). Waste *treatment* and energy for cooking, heat, and power associated with the private homes was outside the scope of this study, as these were estimated to be insignificant and similar for all meal types. The impacts included in the Stepwise 1.05 method are human carcinogenic and non-carcinogenic toxicity [chloroethene-equivalent (eq)], respiratory inorganics (particulate matter with a diameter of ≤ 2.5 mm), ionizing radiation (Bq, the SI-derived unit of radioactivity, C_{14}-eq), ozone layer depletion (chlorofluorocarbon 11), aquatic and terrestrial ecotoxicity (chloroethylene triethylene glycol-eq), nature occupation (agricultural land), global warming (CO_2-eq), acidification (area unprotected ecosystems), aquatic (NO_3-eq) and terrestrial (area unprotected ecosystems) eutrophication, respiratory organics (person · ppm^{-1} · h^{-1}), photochemical ozone effects on vegetation (m^2 · ppm^{-1} · h^{-1}), nonrenewable energy (MJ primary), and mineral extraction (MJ extra). However, for clarity, only data for the three most important impact categories in monetized terms (respiratory inorganics, nature occupation, and global warming) were presented separately in this study, along with the sum of the 13 other monetized impacts (Figs. 2 and 3).

Though there will always be uncertainties associated with monetization of environmental impacts, these are less important in this study where the focus is on the relative differences

[1] https://www.fcrn.org.uk/research-library/danish-ethics-council-report-describes-beef-climate-damaging-food-and-calls-beef

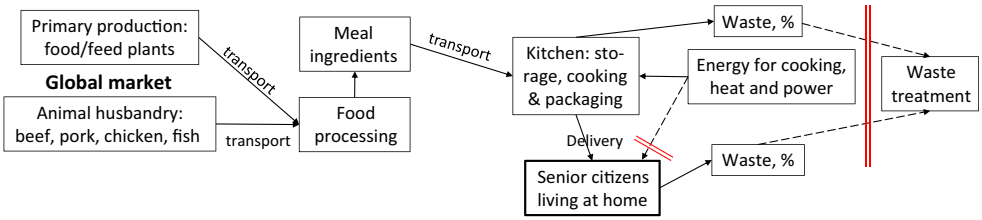


Fig. 1 General flow diagram of the meal-delivery-chain from soil to the senior citizens

between meal categories (beef, pork, chicken, fish, vegetarian) rather than on absolute values. All environmental impacts were calculated according to the ISO standard 14040 (2006). The functional units (i.e., references) were mass, energy content (MJ), or protein content in manufactured meals. The energy and protein contents of the ingredients were taken from the Danish FRIDA food database (2016). Energy and protein content as well as total carbohydrate, dietary fiber, and total fat in 100 g of each meal are given in Table 1 and further detailed in Electronic Supplementary Material no. 2 together with details on impact assessments of each meal.

2.3 Cost of ingredients

Based on recipes for the 47 main meals, combined with food service prices for the ingredients, the ingredient costs per serving for all main meals were calculated excluding VAT. Price data were for the period 2013–2014, supplied from one of the major Danish suppliers of groceries for food service operators.

For ingredients, where more than one variety was available from food service suppliers, the variety with the lowest price per kg was selected for the price calculation. This implies that the price estimates represent the lowest possible ingredient cost for the respective meals. If further requirements to the ingredients are stated (e.g., that they should be organic, should be domestically produced, should be semi-processed, etc.), the unit prices will tend to be higher.

The cost data for the 47 main meals include the cost of ingredients and of cooking and storage, but not full information about other energy use, personnel hours, depreciation and maintenance of kitchen facilities, waste management, etc. Data from Danish municipal kitchens for provision of meals to the senior citizens suggest that ingredients on average constitute 30–40% of the total cost of meal service. This might suggest that the capacity costs would constitute around 2.0–2.5 € per meal and delivery 0.5–1.0 € per meal—a total of around 3 € per meal—which should be added to the cost figures in Table 3, although there is of course some variation in the time and energy requirements across meals.

2.4 Packaging and delivery

The meals were delivered on plastic trays for food with an average weight of 23 g covered with 1 g of plastic film. Small diesel vans, e.g., Fiat Ducato or Iveco were used to deliver meals from the kitchens to its customers driving the shortest possible overall route.

2.5 Waste

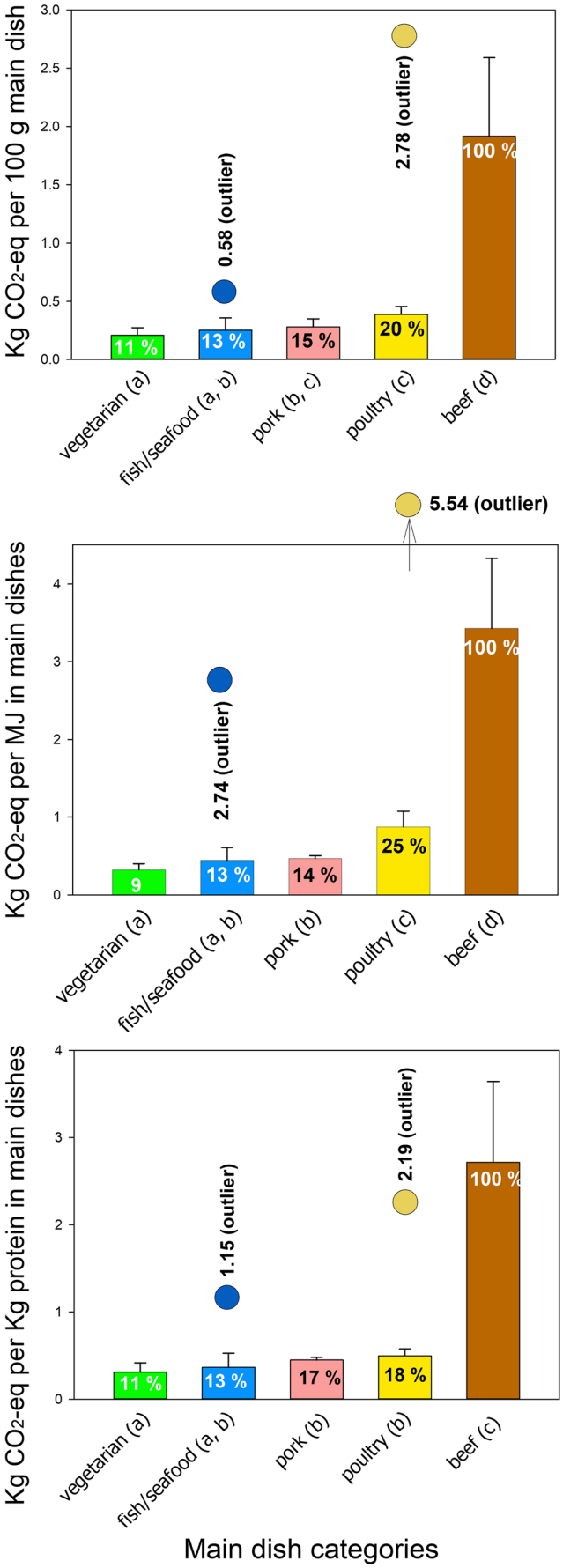
Waste at the kitchen level was estimated in the questionnaires to the meal service providers as normal production waste, e.g., bones and fat from meat, bones and shells from fish/seafood, and peel and kernels from vegetables and fruits, and as other waste, e.g., meals lost on the floor, or not received because customers were not at home.

Waste at the consumer level was estimated from 291 filled in questionnaires from senior citizens enrolled in meal catering service. Surveys were collected from central Copenhagen ($n = 89$) and northern Jutland ($n = 202$). Three questions focused on waste from delivered meals. The first question ("how often do you through away leftovers from the food delivered?") was rated on a 5-point non-dichotomous ordinal scale: 1 = never, 2 = a few times a year, 3 = a few times a month, 4 = a few times a week, 5 = daily. For quantification, the answers were translated as 0, 2, 24, 104, and 264 times a year. The second question ("please indicate how much and which type of the delivered food you throw out on average") was rated on a 5-point interval scale with anchored descriptors (1 = 0–19%, 2 = 20–39%, 3 = 40–59%, 4 = 60–79%, 5 = 80–100%). For quantification, the answers were translated as 10%, 30%, 50%, 70 and 90%. The third question was open-ended: "If you throw out delivered food, please write what it is you usually throw out (meat, vegetables, potatoes...)?"

3 Results

3.1 Global warming impact

The global warming impact (GWP_{100}) caused by the primary production of ingredients and preparation in the central kitchens of the 47 main meal recipes relative to three functional units, i.e., mass, energy and protein content are given for each meal in the Electronic Supplementary Material no. 2. Figure 2 summarizes the results, showing that main courses with beef have *by far* the highest impact with *any* of the three functional units. The choice of functional unit (FU) depends on the purpose of the study. The average environmental impact of main meals with beef had a 6.6–6.8 times higher



◀ **Fig. 2** Global warming impact of 47 main meals divided into five meal categories given in Kg CO_2-eq per 100 g (top figure), Kg CO_2-eq per MJ (middle figure), and Kg CO_2-eq per Kg protein in the main meals (bottom figure). The vertical lines above the columns indicate the standard deviation of the means. The numbers inside each composite bar refer to the average impact of each of the five meal categories relative to the average impact of main meals with beef. The arrows in the middle figure indicate that this poultry outlier (roast duck with potatoes and red cabbage) is outside the ordinate scale. The letters in parenthesis after meal category names on the abscissa axis indicate meal categories with similar GWP impact, i.e., categories that are not significantly different (*t* test, $P < 0.05$). As an example, fish/seafood and pork are not significantly different as indicated by "b". "d" on the other hand indicates the impact of beef meals differ significantly from all other meal categories

impact (depending on the FU) than the average impact of the other four meal categories, and on average a 9.1–11.1 times higher impact than the average vegetarian meal. Differences among the non-beef meals were smaller.

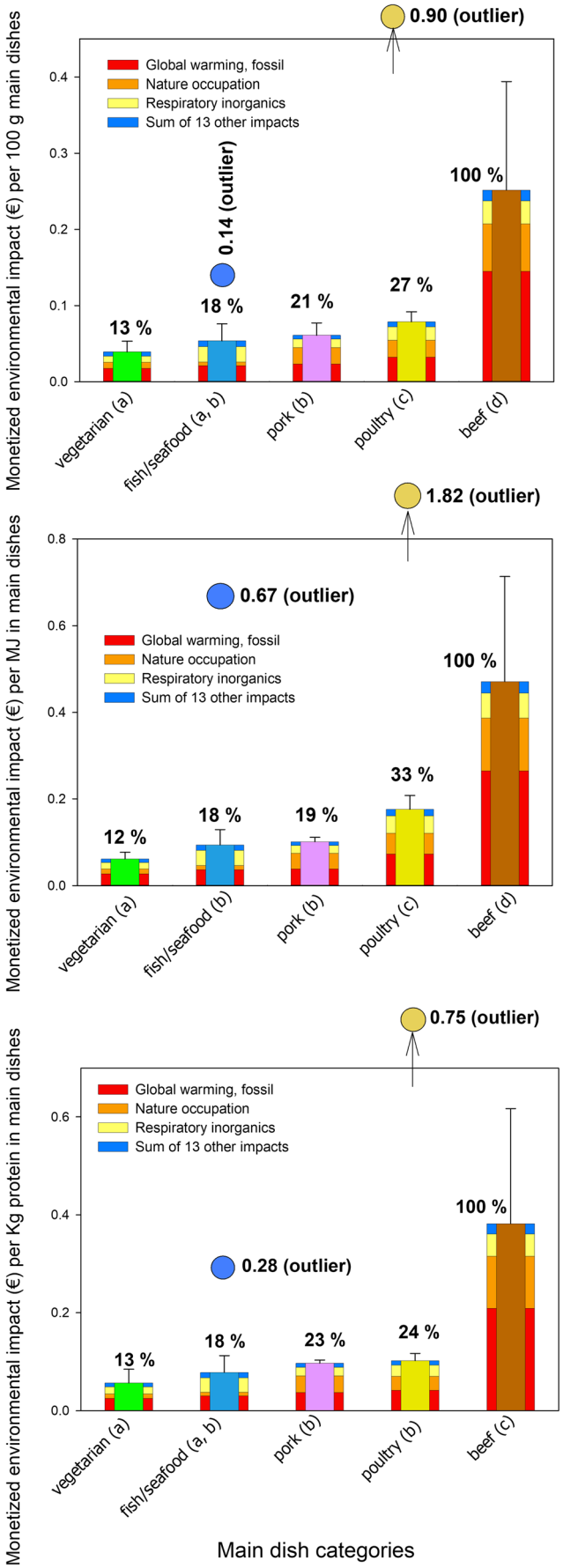
Statistical analyses show that the global warming impact of vegetarian and fish/seafood meals is not significantly different with any of the functional units. Similarly, fish/seafood and pork meals do not show a significantly different impact with any of the functional units, and with protein as the FU, even poultry meals share impact class with fish/seafood and pork. Outliers like the examples given for fish/seafood (grilled lobster with red bell peppers) and for poultry (roast duck with potatoes and red cabbage) are not included when comparing average impact values of meal categories. However, such outlier meals are only on rare occasions served to the meal service recipients in this study.

3.2 Monetized overall environmental impact

Environmental impact caused by the production and preparation of the 47 main meal recipes in terms of the monetized overall environmental impact (€) relative to the three functional units mass, energy and protein content are given in the Electronic Supplementary Material no. 2. The monetized overall environmental impact is the sum of the monetized impacts of the global warming, nature occupation, respiratory inorganics, and the sum of the remaining 13 impact categories all specified in Section 2.2.

Figure 3 summarizes the results, once again demonstrating that main courses with beef have *by far* the highest impact using *any* of the three functional units. The average environmental impact of main meals with beef had a 4.9–5.1 times higher (depending on the FU) impact than the average of the four other meal categories, and on average a 7.7–8.3 times higher impact than the average vegetarian meal. Differences among the non-beef meals were smaller.

Statistical analyses show that the global warming impact of vegetarian and fish/seafood meals are only significantly different with energy content as the FU, where vegetarian meals have about 2/3 the environmental impact of fish/seafood and



◀ **Fig. 3** Monetized environmental impact of 47 main meals divided into five meal categories (using meal category colors at the center of each column as in Fig. 2) given in Euros per 100 g (top figure), Euros per MJ (middle figure), and euros per Kg protein in the main meals (bottom figure). The vertical lines above the columns indicate the standard deviation of the means. The numbers above each composite bar refer to the average impact of each of the five meal categories relative to the average impact of main meals with beef. The colors at both edges of each column indicate the contribution to the impact by global warming, nature occupation, respiratory inorganics, and the sum of 13 other impacts, respectively. Arrows indicate that poultry outliers are outside the ordinate scale. The letters in parenthesis after meal category names on the abscissa axis indicate meal categories with similar GWP impact, i.e., categories that are not significantly different (*t* test, $P < 0.05$). As an example, fish/seafood and pork are not significantly different as indicated by "b". "d" on the other hand indicates the impact of beef meals differ significantly from all other meal categories

pork meals. With protein content as the FU, vegetarian meals have 60% of the impact of pork and 56% of poultry meals. Fish/seafood and pork meals do not have a significantly different impact with any of the FUs, and with protein as the FU even poultry meals share impact class with fish/seafood and pork.

Both edges of each column in Fig. 3 illustrate how the monetized environmental impact is made up (nearly independent of the FU) of a 48–49% contribution by global warming, 25–26% by nature occupation, 18% by respiratory inorganics and 8% by the sum of the 13 other impact categories (Section 2.2). However, these ratios vary between individual meals in all meal categories (data not shown). Monetized global warming impacts are dominating applying all FUs and for all meal types, except for fish/seafood where respiratory inorganics are of similar importance as global warming. Catching fish implicates very little nature occupation, and mainly fuel for fishing boats and power for freezing the catch. With energy content as the FU, poultry has nearly twice the environmental impact of both fish/seafood and pork, while with protein as the FU, the environmental impact of these three meal categories does not differ significantly.

3.3 Average meal

Based on the production data from the five central kitchens, the average (de facto) main meal served to the senior citizens is composed of 1% vegetarian meals, 10% fish/seafood, 59% pork, 10% poultry and 20% beef meals. The global warming

Table 3 Average ingredient cost of a meal in each of the five categories

Meal category	Vegetarian	Fish/seafood	Pork	Poultry	Beef
Average price ($N = 9$)	1.01 €^{a,b}	1.58 €^{c,d}	0.92 €^{a}	1.70 €^{c}	1.32 €^{b,d}

The letters a, b, c, and d indicate that the average price of meal categories with the same letter does not differ significantly from each other (*t* test, $P < 0.05$)

impact of the composition average meal (480 g) is calculated as 2.21 kg CO_2-eq and the overall monetized impact as 0.37 € per meal.

3.4 Impact of waste

The five kitchens reported food waste during and after production of up to 1–5% for meat and fish, up to 1–10% for vegetables and fruit, and up to 1–2% for other ingredients. Based on this, the overall food waste at the kitchen level was assumed to be in the range 0.5–5% for the five kitchens. The impact of waste per main meal at the kitchen level was 0.03–0.18 kg CO_2-eq and 0.007–0.023 € depending on the amount and type of wasted product.

The annual waste of main meal components at the dependent senior citizen level was estimated based on the 291 questionnaire respondents having 260 meals per year as 300 kg potatoes, 120 kg gravy, 550 kg vegetables and 400 kg unspecified meat and 30 kg fish. The GWP of this was 8000 kg CO_2-eq, and the monetized overall environmental impact was 1250 €. The typical meal service would deliver five main meals a week for 52 weeks a year, or 260 meals. 96,928 meals were delivered to the 291 senior citizens respondents to the questionnaire described in Section 2.5. These have an estimated impact of 214,000 kg CO_2-eq and 36,000 €. The impact of waste per main meal at the individual level was 0.031–0.329 kg CO_2-eq and 0.006–0.041 € depending on the type of meal. The direct impact of this waste has already been included at the production level of the flow, as it has been produced and delivered. Nevertheless, the senior citizens will have to compensate for the lost intake caused by waste (leftovers) by eating more of other foods. This waste is therefore included as a small indirect impact in Fig. 4 to illustrate its relatively small impact.

3.5 Packaging and delivery

For three-compartment plastic trays (23 g) and 1 g plastic film for cover, the environmental impact associated with packaging added a global warming impact of 0.07 kg CO_2-eq and a monetized overall environmental impact of 0.006 € per meal. This is insignificant in relation to the overall impact of meal service. All comparisons with, e.g., recyclable trays are therefore irrelevant.

The delivery vans typically travelled about 1 km (a range of 0.92–1.56 km) for delivery to each customer. Each delivery consisted of a single, and up to seven main meals, and in addition one or several dessert. The environmental impact of meal delivery by medium size vans ranged from 0.026 kg CO_2-eq and 0.005 € per meal, and up to 0.435 kg CO_2-eq and 0.09 € per meal depending on the average distance between customers (0.92–1.56 km) and the frequency of meal delivery (1–7 times per week). Based on these data, we calculated a minimum and a maximum impact of meal delivery (Fig. 4).

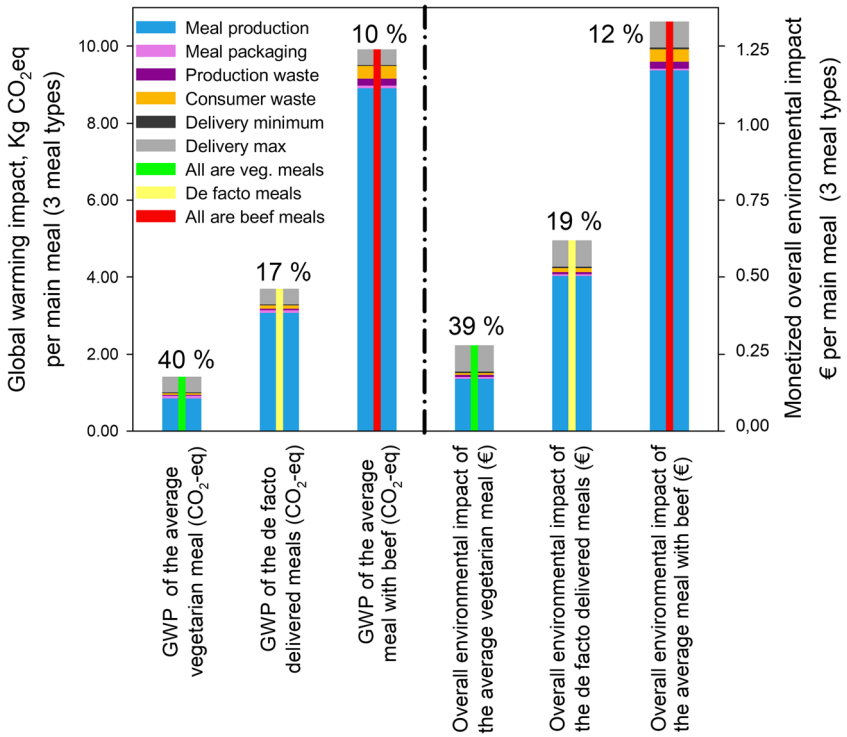


Fig. 4 The total global warming impact (three left columns) and overall monetized environmental impact (three right columns) of Danish meal service for average vegetarian meals (columns with a green vertical line, $n = 9$), de facto delivered meals (bar no. 2 and no. 5 with a yellow vertical line, $n = 45$), and average meals with beef (red vertical line, $n = 9$). The total impact is made up of contributions from meal production, packaging, waste, and delivery of the meals from the kitchens to the consumers. The percentages above each column signify the share of packaging, waste, and delivery

3.6 Cost of ingredients for each meal

The cost of ingredients for each meal can be found in the Electronic Supplementary Material no. 2, and average prices of the five meal categories in Table 3. The average price of ingredients for main meals does not differ significantly (*t* test, $P > 0.05$) between vegetarian and pork meals, between vegetarian and beef, between fish/seafood and poultry meals, and between fish/seafood and beef meals. On average, pork and vegetarian meals are cheaper than meals with fish/seafood and poultry. Ingredients only account for 20–40% of total costs of a main meal, and there may be some room for modifying recipes regarding ingredients, without altering total costs dramatically. For an estimate of the overall cost of meals, the capacity and delivery costs should be added to the ingredient cost in Table 3.

3.7 The impact components of Danish meal service

To reduce the total impact of a meal management system, it is necessary to look at all links in the chain (Fig. 1) (Jungbluth et al. 2016). Figure 4 gives an overview of the total impact of Danish meal service with the two impact categories used in this study, and in this case using mass as the common FU for all materials and activities. Average meals (bars with a yellow vertical line) signify the de facto delivered meals, i.e., 1% vegetarian meals, 10% fish/seafood, 59% pork, 10% poultry and 20% beef meals. A de facto meal delivered to an average-dependent senior citizen living at home is associated with an annual environmental impact of 1033 kg CO_2-eq and a monetized overall impact of 1415 €, i.e., 17 and 19% respectively of the overall impact. If the delivery included vegetarian meals only (bars with a green vertical line), the relative impact of packaging, waste and delivery would be large (40%, 39%), while in case the delivery included only beef meals (bars with a red vertical line), the relative impact of packaging, waste and delivery would be small (10%, 12%).

4 Discussion

4.1 Seven strategies to improve the sustainability of Danish meal service

In this section, we discuss which strategy is most important on the path to improving the sustainability of meal service.

4.1.1 First strategy: cut down on beef meals

Twenty percent of the delivered meals in this study contained beef. Beef meals have a seven times higher impact on global warming (Section 3.1) and a five times higher monetized overall environmental impact than the average of the other meal categories (Section 3.2). The most effective and often the only available strategy to reduce the environmental impact of the Danish meal service is to reduce the delivered number of beef main meals. This reduction can come about by the kitchens producing fewer meals of this type, and/or by encouraging the older person to choose fewer beef meals. If the share of beef meals delivered by the meal service came down from the present 20 to 10%, the global warming impact (kg CO_2-eq) and the monetized overall environmental impact (€) of the meal production would be reduced, depending on the FU by 25–26% and 19–20% respectively.

4.1.2 Second strategy: choose the less impacting beef

In view of the relatively large variability of the environmental impact of beef meals (larger than the other meal categories; Figs. 2 and 3, and the Electronic Supplementary Material no. 2). To be effective, this strategy implies a need to calculate the impact of *all* beef meals produced by each kitchen.

4.1.3 Third strategy: beef-free Monday

Meatless Monday is an international non-profit initiative founded in 2003 that encourages people not to eat meat on Mondays to improve their health (following the USDA nutritional guidelines) and the global sustainability. In our study, we found no effective meal choice strategies to reduce the environmental impact among non-beef meals. A substitution with poultry and pork meals with fish or vegetarian meals reduce the impact very little. But on the condition that one beef-free day a week does not result in having more beef than usual the rest of the week, this is a third tangible strategy to improve the sustainability of meal service, though it may be seen as a variation of the first strategy (Section 4.1.1) with significant reduction of environmental impact.

Serving all costumers a fish/seafood meal 1 day a week rather than the present mix of all five main meal categories would reduce both the global warming impact and the monetized overall environmental impact of the meal production by 8% independent of the FU. One vegetarian day per week instead of status quo would reduce both the global warming impact and the monetized overall environmental impact of meal production by 9% independent on the FU. A beef-free Monday thus serves nearly as well as a meat-free Monday in protecting global sustainability.

Vegetarian meals may be less preferred for the current generation of senior citizens, especially in rural areas (Johansen et al., in preparation). In order to create acceptance for more vegetarian and fish/seafood meals, the central kitchens will have to focus on innovation, meal palatability and customer satisfaction. Meals based on vegetable protein can be more satiating than meals based on animal protein (Kristensen et al. 2016). Even when met with satiating and palatable new

meals, the older people may not appreciate or even notice the taste, as they with their reduced sense of taste are more likely to choose their meals based on habits than on palatability.

4.1.4 Forth strategy: calculate impact of all meals

A forth strategy to increase the sustainability of meal services would be to calculate the sustainability of all meals produced by a given meal service, and either modify the most impacting meals in all categories, or offer them less frequently. In that way, the older people could eat most meals in all categories that they know and are used to eating. However, selection of the most sustainable recipes among all meal categories is a complex task outside the scope of this study.

4.1.5 Fifth strategy: beef tax

As a strategy to reduce the environmental impact of food consumption, the Danish Council of Ethics suggested raising the beef prices by taxation (Lykkeskov and Gjerris 2017). If this were to come true, financial reasons would force Danish meal services to decrease the number of beef meals they offer. That would be a fifth strategy to reduce the impact of meal service, and the civil societies' overall environmental impact caused by food. Such taxation with require a larger analysis on beef consumption for the whole population in order to convince policy makers on the environmental impact of such governmental intervention.

4.1.6 Sixth strategy: weekly meal deliveries

The meal service business involved in this study have an interest in knowing how much they can improve their overall sustainability by focusing on packaging, food waste or delivery strategies. As shown in Fig. 4, packaging, waste and delivery make up a little less than 20% of the overall impact of the meal service with the de facto combination of delivered meals and with both impact categories. If more sustainable meals are delivered (i.e., all vegetarian), the packaging, waste and delivery would make up a larger share (39–40%), and with less sustainable meals (e.g., all beef), a smaller share (10–12%) of the overall sustainability (Fig. 4). Reducing the impact caused by packaging, waste and delivery could be a sixth strategy for improving meal service sustainability. However, these activities are often non-negotiable.

The largest impact is caused by the delivery vans, if, and *only* if the meals are delivered *daily*, with *low-mileage* vans and *long average delivery distances* ("delivery max" in Fig. 4) rather than bundled with all meals for a week's supply, energy efficient vans and best-possible routing ("delivery minimum"). For the de facto delivery of meals, converting daily delivery to weekly delivery reduces the global warming impact of meal service by 11% and the monetized overall environmental impact by 14%.

An additional impact is food waste at the consumers (Fig. 4). This potentially makes up 2% of the overall impacts for the de facto delivered meals (3% if all meals were beef meals). This potential impact reduction if this waste could be prevented is small and possibly be non-negotiable. Food wasted at the homes of the senior citizens is typically compensated by additional intake of snack meals to satisfy their energy needs. Similar to Cerutti et al. (2018), we found the impact of packaging to be negligible.

4.1.7 Seventh strategy: restrict outliers

Finally, it is important to avoid, or only enjoy a few times a year, certain meals with extremely high environmental impact, such as the outliers exemplified in Figs. 2 and 3.

4.2 Large number of meals

Due to the very large number of meals produced and delivered by the meal catering companies, a focused selection of meal supply by the management would improve the overall environmental sustainability of the food sector. The five kitchens in this study annually produce and deliver more than 1.2 million main meals (Table 2) to dependent senior citizens living at home with an average impact of delivered meals of 3.7 kg CO_2-eq/meal (Fig. 4), resulting in a total annual impact of 4580 t CO_2-eq. Applying the first strategy to reduce the global warming impact of meal service by 25%, the five meal providers would save 1140 t CO_2-eq per year. Such relatively easy implementable measure equals the annual emission by over five hundred passenger cars (Euro 5 emission standard).

4.3 Choice of functional unit and impact category

Which functional unit and which impact category is the best to point the kitchens towards meals with the lowest environmental impact? The answer to the first question depends on the *purpose* of the main meals, whether they are meant to improve the energy or protein content of the daily food intake of the old adults, or in this study both. There is increasing focus on the choice of FU when LCAs are used to compare foods (Smetana et al. 2015; Salou et al. 2017). Recently, Sonesson et al. (2017) pointed out that protein quality might be an even better FU that protein quantity. The most common FU in LCA studies, mass (kg), was included in this study to be able to calculate the others, but it is meaningless in selecting the most sustainable main meals, with the purpose of delivering *both* energy and proteins to the senior citizens.

The GWP is the dominant environmental impact of main meal production, but except for beef meals, it makes up a little less than half of the average monetized overall environmental

impact of all meals (Fig. 2). Therefore, the answer to the second question is that the sum of the monetized impacts of all 16 impact categories is the best environmental indicator, since it covers the overall environmental impact better than any single category, even the GWP.

While the strategies to improve the sustainability of the Danish meal service are relatively independent of the applied functional unit, Figs. 2 and 3 demonstrates how the choice of FU affect the numbers for absolute environmental impacts and the ratio of impact of any given meal category to another. Poultry-based meals show the largest variation caused by the choice of FU. The impact of poultry varies more relative to beef than the other meal categories.

4.4 The price aspect

Based on the present selection of recipes, substituting main meals with beef with the more fish/seafood and vegetarian meals will not significantly benefit the ingredient cost (Table 3). More pork would lower the cost, while more poultry would increase the cost. The *total* cost of any meal include the capacity cost and delivery costs, which were estimated to be around 3 € per meal. When these capacity and delivery costs are included, the relative difference in cost of producing different meal categories is reduced. If ingredient prices is an issue, we recommend looking at individual recipes rather than considering meal categories.

In view of the environmental impact of disposable plastic trays (Section 3.5) for meal service delivery compared with the environmental impact of producing the meals, recyclable trays have been suggested in a revision of meal services. However, the impact of plastic trays is so low that any impact reduction from switching to recyclable trays would be meaningless. An implicit study of this is therefore outside the scope of the present study.

Weekly delivery of meals to customers rather than daily improves sustainability, and decreases transport cost, but it may impose increased expenses for storage and preparation at the homes of the senior citizens. Most likely, however the senior citizens have their refrigerators/freezers running anyway. This was outside the scope of our study.

4.5 Priorities in meal catering

Besides the price of ingredients, the main priority in meal catering for senior citizens must be based on *taste/acceptability* (it is important to encourage the older people to eat and drink; Nordin 2017), *health* (older people are more vulnerable), and *environmental impact* (food is a major contributor to our overall environmental impact)—in that order—but without the meal service neglecting *any* of the three aspects. Fortunately, low environmental impact often follows a positive health impact of foods (e.g., Springmann et al. 2016), and monetized health impact has been shown to be more important than the monetized environmental impact for the New Nordic Diet (Saxe, 2014; Jensen et al., 2015).

The most effective strategies to reduce the environmental impact of the Danish meal service all include less beef. Lowering beef consumption may have positive health benefits for the senior citizens (Aune et al. 2017; Wolk 2016). The task of increasing sustainability of the meal service by altered diets is an important challenge for the meals on wheels caterers as well as for meal service in nursing homes.

5 Conclusions

The average environmental impact of main meals with beef has a 5–7 times higher environmental impact than the average impact of the other four meal categories, and an 8–11 times higher impact than the average vegetarian meal. The variation in impact depends on the chosen functional unit and impact category.

The most important strategy for reducing the environmental impact of Danish meal service is to either reduce the number of meals with beef, and/or limit all meals to the most sustainable of their kind. The strategy of having a weekly fish/seafood or vegetarian day only improved the overall sustainability when it reduced the number of meals with beef. Vegetarian meals are only a little more sustainable than fish/seafood. Packaging, food waste and delivery of meals play a minor role in the sustainability of Danish meal service, and the most efficient strategy to reduce the environmental impact of those activities would be to deliver all meals on a weekly basis rather than daily.

This study suggests seven strategies to reduce the environmental impact of Danish meal services in terms of global warming impact and monetized overall environmental impact:

1. Cutting the frequency of producing/ordering main meals with beef in half will reduce impacts by 25–26% and 19–20%, respectively, where the small ranges mirror differences according to the applied functional units.
2. Producing/ordering only beef meals from the better half of the beef recipes will reduce impacts by 6 and 5%, respectively.
3. Establishing a weekly beef-free day for all recipients and serving fish/seafood or vegetarian will reduce impacts by 8 or 9% for both impact categories. The increased sustainability is mainly due to the indirect effect of having less beef.
4. Calculating environmental impacts of all meals and selecting to produce/order the more sustainable within each category more often. This strategy must be calculated for each meal service separately, which is outside the scope of this study.

5. Imposing a national beef tax as proposed by the Danish Council of Ethics in 2017.
6. Converting daily to weekly deliveries will reduce impacts by 11% (global warming) and 14% (monetized overall environmental impact), respectively, and eliminating all waste of de facto meals reduce impacts by 2%.
7. Restrict production of meals in all meal categories with extremely high impact (outliers).

The main advice in order to improve the sustainability of the meal service is to reduce the production of beef meals by one or more strategies. The only other way to improve sustainability of meal service is to deliver meals on a weekly rather than on a daily schedule. However, selecting more meals in all categories (particular beef) with the smallest possible environmental impact will have by far the largest effect.

In view of the large differences between the less and the most environmental harmful meals, it is advised that public and private providers of meals for vulnerable senior citizens (and other population groups) make an environmental inventory of all their meals, in order to offer not only the tastiest, healthiest and most attractive, but also the more sustainable meals. A conscious diet choice is a proven path towards greater sustainability (and health), not just for meal services but also for society as a whole.

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